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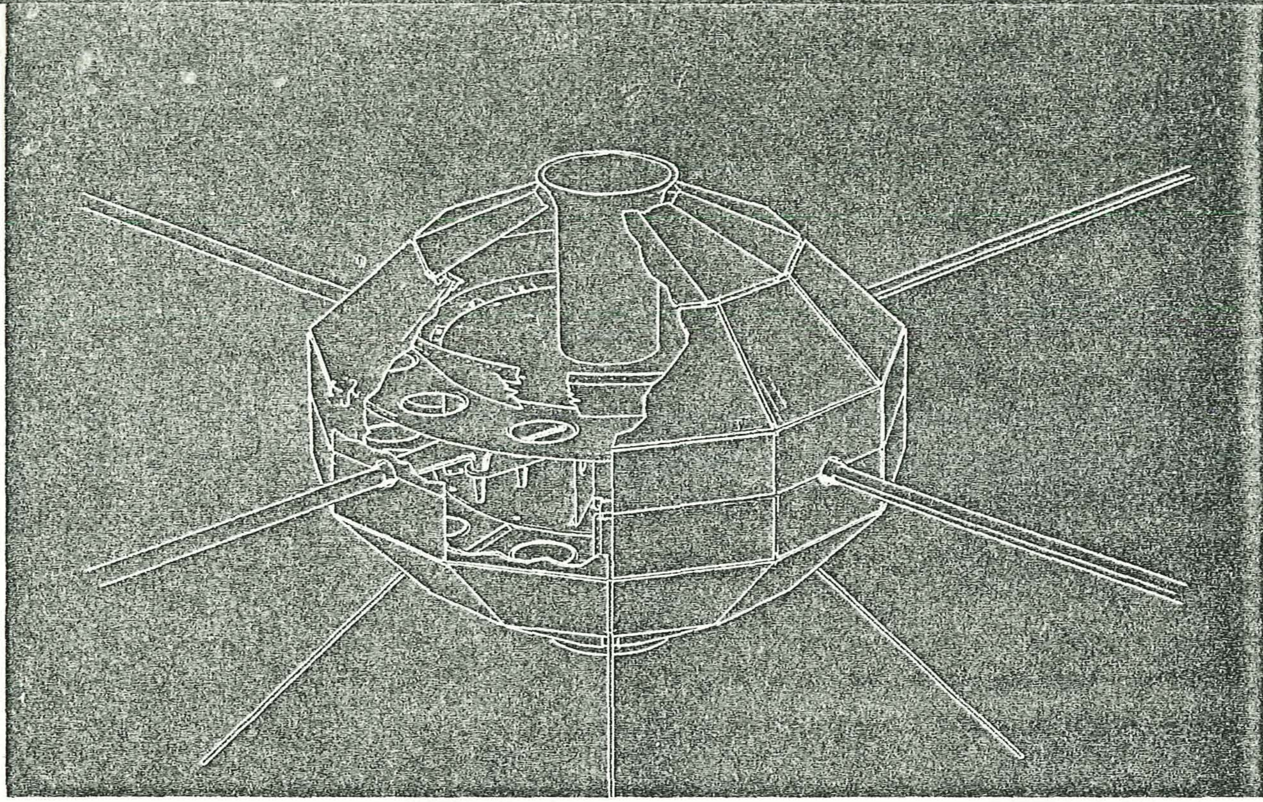

Figure 1. The S27 Spacecraft for the ionosphere sounding experiments — cutaway view.

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CANADIAN SPACE ELECTRONICS

The Canadian swept-frequency ionospheric sounding satellite

. . . . this article from the Defense Research Telecommunications Establishment reveals details of the electronic system of the S-27 satellite . . .

by R. K. Brown*

Introduction

Scientists of the Telecommunications Establishment of the Defense Research Board (DRTE) have been studying the earth's ionosphere for many years. These studies have been directed toward both a better understanding of the fundamental properties of the ionosphere and the application of this knowledge to communication problems. Perhaps the most widely used experimental method for making such studies is the swept frequency ionospheric sounder. This method provides a wealth of information at all altitudes up to that of maximum ionization (the F_2 layer maximum) but not beyond.

This limitation suggested the desirability of instrumenting a satellite to sound the ionosphere from above and when the United States invited suggestions for satellite-born experiments, the Canadian Topside Sounder proposal was made. Final arrangements were made with the National Aeronautical and Space Administration (NASA) and it was agreed that DRTE would provide the spacecraft (satellite) with complete instrumentation, Canadian telemetry stations for receiving and recording data and a data reduction center to convert the recorded data to suitable ionograms. NASA has agreed to provide technical consultation and assistance, final environmental acceptance testing, the use of the world-wide Minitrack chain for satellite tracking, and the recording of ionospheric data outside Canada, and the rockets and range facilities necessary to place the spacecraft in orbit.

This report will be concerned mainly with the Topside Sounder satellite with only brief references to other DRTE responsibilities.

Spacecraft electronics

In addition to the ionospheric sounder which will carry out the primary experiment, the instrumentation includes several other electronic sub-systems. Two telemetry systems will transmit data directly to ground

*See page 30

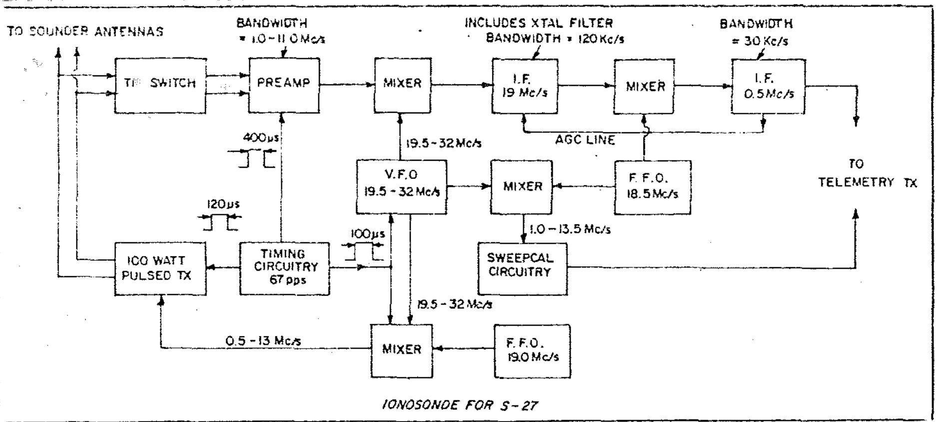
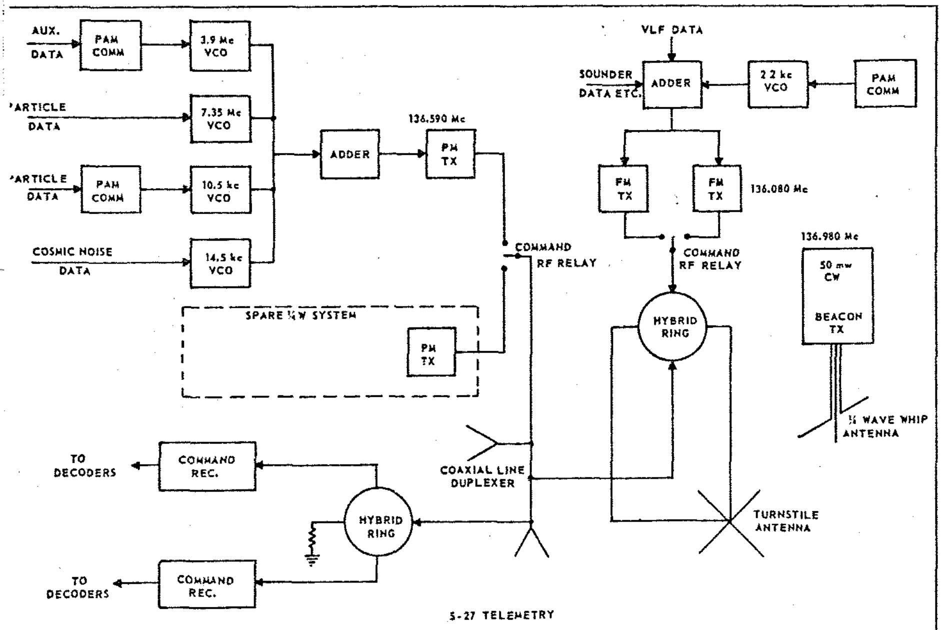


Figure 2. *(left) Block diagram of the ionosonde system of the S-27 satellite*
Figure 3. *(lower left) Diagram showing the satellite's telemetering system.*

stations, an unmodulated beacon transmitter, operating continuously, will enable the satellite to be tracked, and a command receiver and decoder also operating continuously, will provide control of the satellite electronic system. Power will be supplied by solar cells and storage batteries. Monitoring circuits will provide information on currents, voltages and temperatures.

Three other experiments, cosmic particle measurements, a very low frequency receiver and cosmic noise measurements are also housed in the spacecraft. These are significant experiments, the results of which are expected to complement the main experiment, but their description is beyond the scope of this report and they



The Author

R. K. Brown *received his BA and MA from the University of B.C. where he was later a lecturer. After some years with the B.C. Research Council he joined DRB as a Scientific Officer. At* **DRTE** *he has made significant contributions to the S-27 satellite project.*

will not be discussed in detail.

The proposed orbit of the satellite, the characteristics of the ionospheric sounder, and of the command and the telemetry systems are shown in Table I. (See page 68)

The Sounder

The sounder is a swept frequency pulsed sounder covering the frequency range 1.6 to 11.5 Mc. A 100 µsec pulse is repeated at a rate of 67 pulses per second and the rate of frequency sweep is approximately 1 Mc per second. The sweep linearity requirements are relatively easy to meet, as will be discussed later. All the essential components are shown in Figure 2. A variable frequency oscillator (VFO) sweeping from 19.5 to 32 Mc is mixed with a 19 Mc fixed frequency oscillator to produce the required frequency sweep. It should be noted here that it is desired to operate the sounder receiver over the frequency range 0.5 to 13 Mc even though the antenna matching networks are efficient only over the frequency range 1.6 to 11.5 Mc. This is done to provide for the reception of cosmic noise over an extended frequency range although the response falls off very rapidly below 1.6 Mc, being approximately 40 db down at 0.9 Mc. The increased cosmic noise intensity at the low-frequency end of the spectrum will partially offset this decrease in the overall sensitivity of the receiving system.

In the receiver the incoming signal is mixed with the swept frequency oscillator and translated in frequency to 19 Mc. An IF amplifier provides 40 db gain with a crystal filter setting a bandwidth of 120 kc. Following the 19 Mc amplifier the ionospheric signal is mixed with the output of a crystal controlled local oscillator operating at a frequency of 18.5 Mc. This results in a second frequency translation to 500 kc. The 500 kc amplifier has a bandwidth of 30 kc and a gain of 60 db. Amplitude limiting is provided to ensure that the signal reaching the wide-band telemetry channel does not exceed a specified value. An envelope detector at the output of the 500 kc amplifier provides the low frequency signal (sounder pulse plus cosmic noise level). Low frequency amplifiers following the detector provide an AGC voltage to control the gain of the 19 Mc amplifier and a cosmic noise telemetry voltage (not shown in Figure 2) proportional to the AGC voltage. This AGC is designed to provide measurements of cosmic noise over a dynamic range of 40 db. The pulse derived from the signal reflected from the ionosphere is passed directly from the envelope detector to the wide-band telemetry channel (see Figure 2).

The low level stages of the transmitter are wide-band transformer coupled amplifiers using the common base connection. A filter with a pass band of 1-12 Mc/sec is included. This is followed by a cascade of four class B push-pull emitter follower stages, the last of which uses four 2N1709 in push-pull parallel.

The final amplifier consists of four class A pairs in push-pull parallel using the common base connection providing 100 watts into a 400 ohm load. This performance is maintained over the temperature range −50°C to +85°C. Stability requirements call for a low impedance drive which is obtained from the class B cascade described above. The power consumption is 4.3 watts the overall power gain is 46 db and the power gain of the final stage is 7 db.

A free running, capacity-coupled multivibrator sets the basic system rate at 67 pulses per second. Capacity-coupled monostable circuits are used to produce fixed time delays and to generate gating and synchronizing pulses.

The frame and line synch pulses are negative-going with pulse widths of 7 msec and 200 microsec respectively. The zero range, transmitter gate and receiver gate pulses are positive-going and have widths of 100, 120, and 400 microseconds respectively. The video format is shown in Figure 5.

Two dipoles, one with a tip-to-tip (including satellite) length of 150 ft., operating over the range of 1.6 - 4.5 Mc and one at right angles to the above, 75 ft. tip-to-tip and operating in the range 4.5 to 11.5 Mc will be used.

These will be driven by balanced wide-band matching networks with insertion loss not in excess of 11 db. Balanced drive will be utilized in order to avoid any unbalance, and hence ensure that the orthogonal dipoles are electrically orthogonal.

In the cross over region around 4.5 Mc/sec radiation will take place from both antennas and the radiated wave will not be plane polarized as for a single dipole, but may be circularly or elliptically polarized depending upon the relative phases of the currents in the two antennas. It is not expected that this phenomenon will seriously degrade the ionograms.

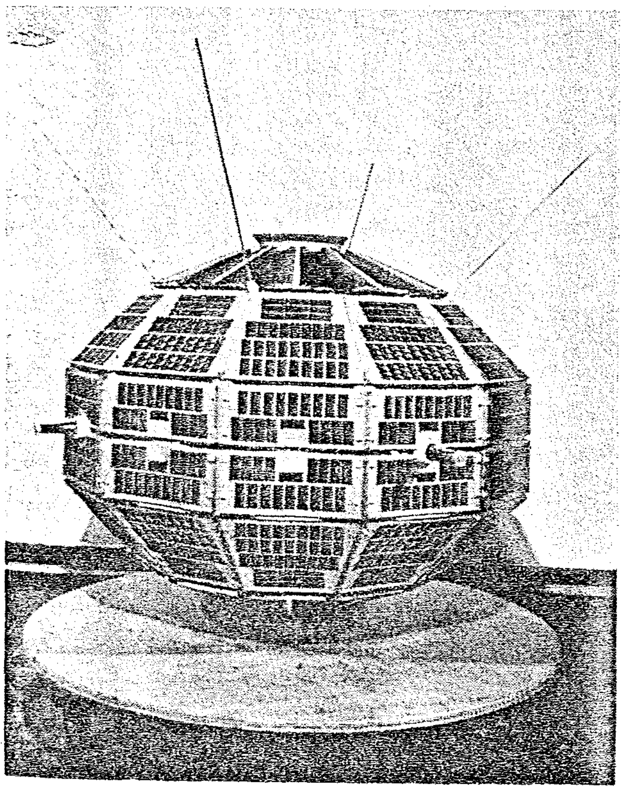


Figure 4. Photograph of the S-27 "Top-side Sounder" satellite.

Telemetry and Beacon — see figure 3

Two telemetry transmitters are to be used, one operating at a power level of 0.25 w at a frequency of 136.590 Mc, and a second with a power output of 2.0 w at a frequency of 136.080 Mc (see Table I). Both transmitters are operated on command only, to conserve battery power. The lower power transmitter is modulated in such a way that it may, in an emergency, be used as a tracking beacon. Both transmitters are duplicated in order that a spare unit may be switched in, on command, in case of failure.

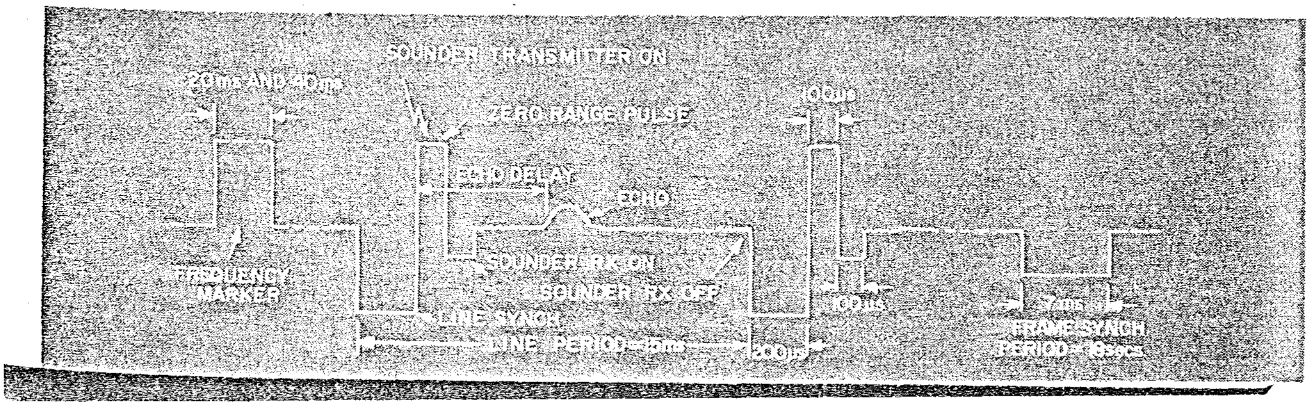
The 0.25 w, 136.590 Mc transmitter is phase modulated by four standard IRIG subcarrier oscillators at 3.9, 7.35, 10.5 and 14.5 kc respectively. The 7.35 and 10.5 kc subcarriers are to be used for the cosmic particle experiment. The 14.5 kc subcarrier will monitor the cosmic noise level during the sounder sweep. The 3.9 kc subcarrier will monitor battery voltages, solar cell charging currents and temperatures. Data inputs to the 3.9 kc, and the 10.5 kc subcarriers are time multiplexed (PAM) using solid state commutators. Total phase deviation of this transmitter is ±0.8 rms radians.

The 2.0 w, 136.080 Mc transmitter will be frequency modulated by the ionospheric sounder echo signals plus marker and synchronization pulses. Signal bandwidth for the above is from ½ cps to 10 kc. A 22 kc subcarrier has been added to this transmitter and will carry information redundant to that on the 3.9 kc subcarrier on the low power transmitter. Peak frequency deviation of this transmitter is ±40 kc.

The telemetry antenna consists of four whips in a turnstile configuration (see Figures 1 and 4). They are driven by a hybrid ring isolator. This antenna is shared by the two telemetry transmitters and by the two command receivers (see Figure 3). The command receivers are isolated by means of a hybrid ring cut to the command frequency which in turn is isolated from the ¼ w 136.590 Mc transmitter by a coaxial line duplexer. All inputs to the antenna will have a maximum VSWR of 1.4:1.

A 50 mw, 136.980 Mc tracking beacon transmitter has been provided for use by the NASA Minitrack network. This transmitter is unmodulated and radiates continuously via a single ¼ wavelength whip mounted on the "top" of the satellite.

Figure 5. Video format of the S-27 ionosonde.



Command System

With the exception of the beacon transmitter and command receiver, all electronic equipment in the satellite will be normally off. When the satellite comes within range of the ground telemetry station, the appropriate spacecraft equipment can be turned on by command. The full electronic system can be turned on with automatic turn off in 10 minutes, or one or more of a number of individual sub-systems depending upon the measurements desired. Command is achieved by the transmission of a radio frequency signal which is modulated by discrete audio tones. Combinations of seven tones are used to achieve a total of 12 commands. The spacecraft contains two command receivers, for redundancy, and appropriate decoding networks. This equipment operates from the "best" battery so that as long as one of the six batteries is operative command can be achieved.

Monitoring Circuits

Battery current measuring circuits permit measurement of the charge or discharge currents of the six battery packs used in the power supply system of S-27. A resistor of approximately 0.5 ohms is inserted between the negative terminal of each battery pack and earth. The voltage developed across this resistor due to the passage of current is amplified by a balanced pair of NPN transistors, the voltage outputs of which are fed to the two commutators for redundant telemetry of battery current information back to the ground. These current measurements provide not only quantitative data on the charge and discharge rates, but also serve to monitor the command operation of the battery pack switching circuit by indicating which battery packs are in use at any given time.

The voltages of the four working packs will be monitored by telemetering the voltages appearing at the four outputs of the battery switching circuit. In order to provide a higher accuracy in the telemetered readings than could be obtained by simple voltage division from these points to the commutator inputs, two six-volt zener diodes are employed in series to subtract a substantially constant 12 volts from the battery pack voltages before telemetry. An appropriate voltage divider then limits the voltage variations of the battery packs to the useful dynamic range of the commutator inputs. The four voltages measured are transmitted redundantly on the 250 milliwatt and 2 watt telemetry transmitters.

The temperatures of 22 points within the satellite will be monitored. The basic measurement technique relies on the change of resistance with temperature of disc-type thermistors. A zener diode regulated voltage is impressed across a resistor is series with each thermistor to obtain an output voltage which varies approximately over the dynamic range of the commutator inputs for the expected temperature range of the satellite. Eleven thermistor circuits have outputs feeding the 250 milliwatt telemetry transmitter via commutator #1, and the remaining 11 will feed the 2 watt telemetry transmitter via commutator #2.

Power Source

Early in the system design a decision was made to use a single voltage level, 15 volts, for all batteries and to derive the voltage rails needed for the various circuits from DC - DC static converters. Consequently, the power source consists of six nickel-cadmium batteries (four operating plus two spares) recharged by silicon solar cells. Four DC - DC converters, one associated with each operating battery, provide the necessary DC voltage levels.

A total of 6480 solar cells, arranged in 144 series groupings of 45 cells each, provide the charging power for four separate 12 battery Ni-Cd battery supplies. The solar cell efficiency (9 per cent), arrangement (aspect ratio 4.25), operational temperature (0°C), together with factors for micrometeorite damage, transmission losses, and safety margin supply an input to the batteries that has a design minimum of 22 watts.

One of the four battery supplies is to provide power for most of the continuously operating circuitry. The remaining three are to operate the command part of the instrumentation. These three supplies have capacities proportionally much larger than necessary when considered in the light of charging power per orbit. This excess capacity will be used to supply sounding power for the greater part of two successive orbits, recharging taking place over many following orbits. Construction techniques developed for presently orbiting satellites have been used in all phases of the power source construction. However, thicker (0.012 inch) than average solar cell cover glasses have been used to protect against higher energy electron damage.

Mechanical design

Spacecraft Design

The shape and general structure of the spacecraft are shown in Figures 1 and 4. Figure 1 shows the internal arrangement. The four sounding antenna modules and the batteries (not shown) are located in the central cylindrical section. The electronic packages (not shown) are mounted on the decks above and below the central section in the space between the thrust tube and the stiffening flange shown cut away in Figure 1. Both figures show the four sounding antennas extending in the equatorial plane and the telemetry turnstile whips. The beacon antenna, not shown here, is a whip mounted at one end of the thrust tube along its axis.

The spacecraft shape approximates an oblate spheroid and the design is a compromise between two requirements: first that the electronic packages be accessible and easily removed; and second that the solar aspect ratio be constant. The aspect ratio is the effective fraction of the total surface area illuminated. A constant aspect ratio is desirable to maintain constant solar cell output power.

Attached to the periphery of the central structure are two half-shell aluminum spinnings which form the satellite shell. Onto this spun shell are attached the solar cell panels and both heat-control end caps. The central structure is attached to the thrust tube through which the entire load is transmitted.

The spacecraft is 42 inches in diameter, 34 inches high and weighs 320 lbs. Roll and pitch moments of intertia of the vehicle prior to sounding antenna extension are 7.9 and 5.5 slug-feet^2 respectively. These values increase to 577 and 255 slug-feet^2 with antennas unfurled.

Sounding Antenna Design

The sounding antenna system consists of crossed dipoles one of which measures 150 ft. tip-to-tip and the other 75 ft. tip-to-tip. Individual poles are therefore approximately 75 ft. long and 37½ ft. long, and are 0.90 inches in diameter. The novel feature of this antenna design is the matter in which it is stowed within the spacecraft in a relatively compact volume. *(see article commencing on page 46, and in particular, Figure 10 on page 48.)*

All four antenna poles are driven out in unison during extension by a single motor and gear train. The shorter poles are declutched from the drive when fully extended while the longer two continue to drive out. The rate of extension of each tube is 0.17 ft. per second.

Continued on page 63

although it will be considered a success if it continues to operate electrically for three months. The orbit passes through the severe radiation of Van Allen belts.

Project RELAY I Satellite

Figure 2 shows the general arrangement of the satellite. External construction resembles an eight-sided barrel, about 32" long and 29" diameter, with eight flat faces. Including the main antenna, which protrudes from the end pointing towards the earth, it is about 4½ feet long. The outside is covered with solar cells, to provide electrical power from the sun's rays. The internal structure is a space-frame constructed from aluminum alloys, and the internal equipment consists of the communications electronics, storage batteries, telemetry equipment, and some apparatus for radiation experiments. The total weight of the satellite will be about 135 pounds, of which the basic structure represents only 10%.

To stabilize its position in space, thus ensuring correct antenna pattern orientation relative to the earth, the satellite has a spin rate of 120 r.p.m. and is equipped with a magnetic ring controlled from the ground which allows small corrections of attitude to be made.

Vital parts of the satellite electronics, designed and built by **R.C.A. Victor, Montreal,** include the Wideband-Narrowband Repeater and the CW Beacon. In addition, the company has been called upon to design and build a Satellite Simulator and to perform overall systems engineering studies and analyses to help determine ground station requirements and satellite component performance.

The Wideband-Narrowband Repeater is the heart of the satellites electronics. This unit receives the weak signals from the ground station, amplifies them, and sends them back to earth to the receiving station. It will handle television, telephony, and data-transmission signals.

Design and development of this unit brought about several significant "firsts" e.g. The first microwave repeater designed in less than one year. The first microwave repeater designed for an airborne environment. One of the first entirely solid-state heterodyne microwave repeaters with the exception of the TWT. The first microwave repeater achieving this degree of miniaturization.

The C.W. Beacon sends out a continuous signal at a discrete frequency. It will be used to locate and track the satellite. Without this facility, it would be impossible to locate the satellite with sufficient accuracy for the ground stations to operate, and is consequently a very vital unit.

The Satellite Simulator. This is a piece of ground equipment used by the Ground Stations to check out their equipment prior to contacting the satellite. The units produced will be distributed around the world to the various governments participating in the project.

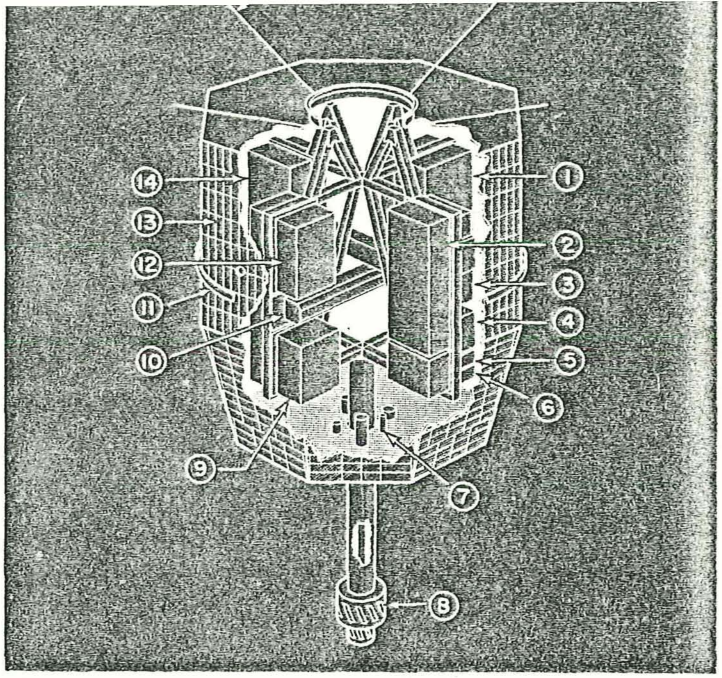


Figure 2. Diagram showing main components of the RELAY I satellite:
(1) Travelling wave tube power supply.
(2) Radiation effects experiment.
(3) Receiver exciter.
(4) Encoder.
(5) Decoder.
(6) Receiver and subcarrier demodulator.
(7) Radiation sensors.
(8) Wide-band antenna.
(9) Receiver and travelling wave tube exciter.
(10) Travelling wave tube.
(11) Attitude control coil.
(12) Travelling wave tube power supply.
(13) Solar cells.
(14) Batteries.
(15) Telemetry antenna.

Canadian satellite

Continued from page 32

Sounding program

Arrangements have been made to turn the satellite on and carry out topside ionospheric soundings at 13 ground telemetry stations located in Canada and around the world.

When all equipment is on, the satellite power consumption is 35 watts. Since the solar cells provide about 10 watts (averaged over 24 hours) when the satellite is in a minimum sunlight orbit the equipment can be operated for only five hours in 24 hours. However, this allows sufficient time for all passes within good telemetry range of all the ground stations. The condition of the batteries will be closely monitored and if necessary the sounding program will be adjusted accordingly.

Each station has a command transmitter and receivers for both the FM and PM telemetry systems. All information, along with a suitable satellite time code, will be recorded in seven channels on half inch magnetic tape. The tapes will be sent to DRTE at Ottawa where a data reduction center will convert the stored information to photographic ionograms and paper chart records (for temperature and battery currents and voltages) as required by the users. The design life of the satellite is one year and since, during the lifetime of the satellite, tape records will arrive at Ottawa at a rate requiring eight hours of processing a day, a very large amount of data will be accumulated. It may be desirable to direct future effort toward some form of automatic or semi-automatic data analysis.

Conclusion

The S-27 is a complex spacecraft containing two primary experiments, the topside sounder and the cosmic particle equipment, and two secondary experiments, the very low frequency receiver and the cosmic noise measurements. Auxiliary equipment includes temperature, voltage and current monitors, power supply batteries and converters, telemetry and command systems

Continued on page 68

Canadian satellite

Continued from page 63

and the beacon. All this equipment is carried in a structure which must be accurately dynamically balanced and must withstand extensive vibration and high accelerations. Finally, an antenna of novel mechanical design must operate successfully in the space environment. Ultra conservative design and extensive and rigorous testing have been used wherever possible to ensure the maximum probability of success.

This project has been made possible through the provision by the National Aeronautical and Space Administration of the Thor-Agena launching rocket and associated range facilities which will be used to inject the S-27 Topside Sounder into orbit in the third quarter of 1962.

TABLE I

S-27 Satellite Characteristics

Orbit	
Circular	625 miles (1000 km)
Inclination	80° toward the east
Sounder	
Transmitter Frequency Sweep	1.6 to 11.5 Mc
Receiver Frequency Sweep	0.5 to 13.0 Mc
Transmitter Power	100 watts pulse
Modulation	100 μsec pulse with 67 cps prf
Telemetry #1	
Frequency	136.080 Mc
Transmitter Power	2.0 watts nominal
Modulation	FM ±40 kc max. deviation
Data inputs	(1) Sounder receiver output (2) Sounder line and frame sync pulses plus frequency markers (3) 22 kc subcarrier carrying redundant data
Telemetry #2	
Frequency	136.590 Mc
Transmitter Power	250 milliwatts
Modulation	PAM/FM/PM ±0.8 radians rms deviation by 4 IRIG subcarriers
Data inputs	(1) Channel 9 - 3.9 kc, 35 point PAM commutator, battery voltage, temperatures, charging currents (2) Channel 11 - 7.35 kc particle detector (3) Channel 12 - 10.5 kc Cerenkov detector (4) Channel 13 - 14.5 kc cosmic noise data, frequency marker pulses
Beacon	
Frequency	136.980 Mc
Transmitter Power	50 milliwatts
Modulation	None
Command Link	
Seven tone AVCO system	12 commands

Acknowledgments

The Sinclair Radio Company, Toronto, Ontario, carried out the electrical design of the sounding antennas and associated matching network, and the telemetry antennas and multiplexer.

The De Havilland Company of Canada, Downsview, Ontario, in close association with the DRTE mechanical design group, carried out the design of the spacecraft structure and the long antennas and extension mechanism.

Antennas

Continued from page 49

Research Laboratories. This unit uses the original Mylar pull-out tape system.

The Model A.1 MK11 unit designed and built for DRTE is shown diagramatically in Figure 10 (See article on page 29, and is being used as an antenna system in the Canadian S.27 Topside Sounder satellite, due for launching late in 1962. Rubber belt-driven, the A.1 MK11 is capable of antenna lengths up to 75 ft., using 0.9 ins. diameter steel element.

The forerunner of the more recent STEM designs is however the Model A.16, 60 ft. erectable boom, a moving guide unit with an element of 0.5 ins. nominal diameter beryllium copper shown in Figure 11. This all metal unit uses no lubrication outside the electric motor package, and has operated satisfactorily after two weeks in a vacuum. These were built for the Applied Physics Laboratory of Johns Hopkins University, and one unit is presently in orbit in the APL TRAAC satellite. The radio lead-off boom is designed to eject a 7 lb. weight attached to its end to operate as a gravity gradient stabilizer*, ensuring that the satellite is correctly oriented in relation to the earth's surface.

*Gravity gradient stabilization may provide a remarkably simple and reliable solution to the satellite attitude control problem. This method could eliminate the involved array of horizon scanners, reaction jets and control systems which possess limited life and reliability.

Figure 12 shows a 30 ft. Model A.18 antenna unit, six of which will be used in each of the S.48 satellites being designed and built by Airborne Instruments Laboratories Inc. These units use a moving drum, tangential lead-off design with 30 ft. of element. The unit weighs 1.5 lbs., and represents a great advance over the original A.2 type.

The Model A.21 unit, presently under construction for the United States Naval Research Laboratories and shown in Figure 13, is the first superlength unit, and is capable of ejecting 1,000 ft., of 0.5 ins. diameter element. However, even longer units up to 5,000 ft. are being considered for space use.

Also under development is an extensible space boom suitable for use with magnetometers and other instruments for the Jet Propulsion Laboratory of The California Institute of Technology.

Conclusions

The STEM family is rapidly expanding into new areas, and there seems no doubt that this new application of a relatively simple concept has enormous potential. Technically, it fulfills a function nothing else can, and innately, who has not wanted, at one time or another to witness the artistry of someone truly succeeding at the Indian rope trick?

Acknowledgments

Acknowledgments are due to the writer's colleagues at De Havilland, Sinclair Radio Laboratories Limited, and to The De Havilland Aircraft of Canada, Limited, for giving permission to publish this article.

**in gravity gradient stabilization the boom, with or without an added mass effectively re-distributes the mass of the total satellite to make it appear like a long beam. In time, usually after about 10 orbits, the unbalance gravity forces acting about the beam result in the alignment of the long axis of the system with a line passing through the center of the earth.*